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AUTOMATED ULTRASONIC TESTING SYSTEM FOR THE CHARACTERIZATION OF DEFECTS IN WELDMENTS

Final Report to

CANMET

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1. INTRODUCTION

This final report describes the work done on all three phases of the project. The purpose of the project was to design and construct an ultrasonic immersion inspection system for research into heavy welds for pressure vessels. The first phase was concerned with the purchase, design, manufacture, and testing of the subsystem and its components. In Phase II, software development and system testing was carried out. Phase III involved the development of more sophisticated software for imaging, and the control of multiple rotating transducers to scan a rotating object. (Detailed task specifications are outlined in Appendix A.)

The original intention to address ultrasonic tomography was dropped because of the uncertain potential for success. In its place, simpler imaging routines giving equivalent results were developed.

The importance of this system being a research tool should be emphasized. A number of automated ultrasonic inspection systems have been described in the literature (1-7), but they have been designed to perform specialized types of inspection. The data acquisition and display methods employed have not offered the flexibility required from a more general-purpose "tool".

2. SYSTEM DESCRIPTION

2.1 HARDWARE

The system hardware can be divided into 4 major subsystems:

i) a scanning bridge and immersion tank,

ii) a scanner controller,

iii) an ultrasonic signal processing subsystem,

iv) a data acquisition, storage and display subsystem.

Two separate computer systems are included, each capable of stand-alone operation. The first, referred to as the "host",

- provides the basic processing power and data storage capabilities,
- coordinates the operations of the various subsystems,
- digitizes and processes acquired ultrasonic data,
- graphically displays the results of this processing,
- provides a user interface through which the operator controls the system.

The second computer system, referred to as the "slave", consists of the programmable scanner controller (which drives the scanning bridge motors) and the ultrasonic signal processing hardware. It also includes an x-y CRT (cathode ray tube) which can be used for real-time display of ultrasonic data during scanning.

A block diagram representing the complete inspection system is shown in Figure 1.

2.1.1 Scanning Bridge and Immersion Tank

The 3-axes scanning bridge provides rectilinear control over the movement of a transducer within a volume of 72" (183 cm) by 48" (122 cm) by 40" (102 cm), and includes precision ground, case-hardened shafts and linear bearings to ensure accurate movement. The movement of the bridge along each axis is controlled by a precision lead screw driven by a 200 step per revolution stepper motor at up to 2 in/sec (5.1 cm/sec) for the smallest axis and 1 in/sec (2.5 cm/sec) for the largest axis. The linear resolution along all axes is 0.0005" (0.01 mm).

The immersion tank is constructed with welded stainless steel plate attached to a square-section tubular frame with a reinforced bottom. Since heavy weldments may occasionally be studied, elongated indexing rails are used; this allows the bridge to be moved away from the open top of the tank to provide maximal access for the loading and unloading of testpieces. The immersion tank and scanning bridge are shown in Figure 2.

The scanner subsystem also includes a stainless steel turntable unit with a 3 jaw chuck, capable of supporting loads of up to 200 lbs. It is a stand-alone unit which can either be used in the immersion tank or removed to allow outside inspection. As with the scanning bridge, the turntable is driven by a stepper motor system, and has a resolution of 0.09 degrees at speeds up to 30 rpm. It is shown in Figure 3a; the mast with rotating transducer disk is shown in Figure 3b.

2.1.2 Scanner Controller

The slave's scanner controller is microprocessor-based, and consists of a Zilog Z80 central processor board with 9 kilobytes of memory and 2 RS-232 serial ports, a parallel input/output board and 2 dual-stepper-motor-driver boards, all interconnected through a standard computer bus. It can also use an 8" floppy disk with 1 MB memory capacity. Its function is to control the movement of the mechanical scanner, thereby freeing the host computer to perform data acquisition and processing. Figure 4 shows the slave system's cabinet, containing both the scanner controller and the ultrasonics subsystem.

The scanner controller recognizes a set of commands which allow a wide variety of different scan patterns to be performed. Any of the four axes X, Y, Z or T (for turntable) may be selected as the scan or index axes, with the step size and velocity specified independently for each. The sampling density i.e., the distance between ultrasonic samples along the scan axis, is also programmable. In addition to the parameter-setting commands there are a number of "action" commands; these initiate movement of individual axes according to the previously specified parameters.

Once an action command has been sent to the scanner controller, the latter proceeds independently until the action is complete or until it receives an abort command. During this time the host computer can be performing other tasks. However, during data acquisition some communication must occur between the host and

the slave so that signal digitization is coordinated with transducer position.

Although normally the scanner controller transmits signals to, and receives commands from, the host system, it may also be used as a stand-alone unit by connecting a computer terminal to one of its RS-232 ports. An operator can then, using the terminal's keyboard, directly enter commands to initialize parameters and perform a scan.

2.1.3 Ultrasonic Signal Processing

Figure 5 shows a block diagram of the ultrasonic subsystem. It provides control of up to 8 transducers (16 in transmit/receive mode), with time-division multiplexing allowing all 8 to share a single analog channel. The subsystem includes the following modules:

i) Pulsers: one per transducer channel; units deliver 300 volt spikes with approximately 30 ns risetime.

ii) Gates: one per transducer channel, each adjustable in width and delay.

iii) Multiplexers: both analog and digital multiplexers, the latter controlling the firing of the pulsers and the former enabling the individual gates and directing the received signal to the selected rf amplifier (below).

iv) RF (Radio-Frequency) Amplifiers: either linear or logarithmic modules are switch-selectable; the linear amplifier has a 15 MHz bandwidth and 40 dB gain; the

logarithmic amplifier allows a signal having a dynamic range of 70-75 dB to be compressed to suit a normal display device with a range of about 20 dB.

v) Logarithmic Attenuator: provides control of system gain over a range of 0 to 69 dB in 1 dB steps.

vi) Video Detector: rectifies and filters the rf echo signal to give a video or A-scan signal; provides additional gain of up to 35 dB, and can be tuned for improvement of the signal to noise ratio.

vii) Peak Detector: outputs a signal proportional to the amplitude of the largest peak contained within the gate.

viii) X-Y Display Interface: receives position information from the scanner controller and peak signal amplitude information from the peak detector; these are processed to give x and y analog outputs which produce a modified C-scan image on either the built-in x-y CRT display (from which it can be recorded using a camera) or on an optional, external x-y chart recorder.

Outputs are provided from each major stage to allow viewing on an oscilloscope or digitization by the host computer.

The peak detector has been included, not to provide output to the host but to allow the ultrasonic subsystem to be used with the scanner controller in a stand-alone mode. The peak detector output can be used as input to either the x-y display interface (as described above) or to other external devices. In the stand-alone mode only one transducer (or transmit-receive pair) is available, which is triggered internally at about 300 Hz.

2.1.4 Data Acquisition, Storage and Display

The host computer is an Ikier Eagle 1, a Multibus-based system utilizing an Intel 8086 microprocessor and 8087 math co-processor and having 768 kilobytes of program memory. The system also includes both fixed- (Winchester) and floppy-disk-based mass storage. A 4 channel serial interface board allows the host to be controlled from a remote terminal as well as driving a printer and providing a communications channel to the slave system. A black-and-white graphics/text monitor is built in to the Ikier cabinet. However, for increased speed, most dialog between the user and the host is carried out through an auxiliary computer terminal.

A DTR (digital transient recorder) installed on the Multibus acts as a high-speed a/d (analog/digital) convertor, permitting the host to digitize and store analog data from the ultrasonic subsystem. The DTR is capable of sampling arbitrary signals at rates up to 20 MHz, while repetitive waveforms may be effectively sampled up to 160MHz. Once triggered, the DTR digitizes 4096 points with a resolution of 1 part in 256. After digitization, the host's data acquisition software can either store the sampled data directly in a file or carry out further processing.

A colour graphics display module, consisting of 3 additional Multibus boards, has a resolution of 1024 by 769 points and can display up to 4 colours simultaneously, chosen from a pallette of

4096. The output from the boards is an RGB signal which is fed to an auxiliary 19" colour monitor. Figure 6 shows the host computer and the auxiliary colour monitor.

2.2 SOFTWARE

The system includes a number of software packages for use on the host computer. First is the operating system, CP/M-86. This can be thought of as the overall "control program" of the system, which provides facilities for users to run all other programs, and to copy, rename, erase, etc. disk files. Most programs designed to run on a CP/M-86 system should run on the Ikier Eagle.

Second are the software "tools" that allow the creation of specialized application programs. These include VEDIT (a text editor), an assembler for the 8086/8087 processors, and FORTRAN 77 and Pascal language compilers. Also included in the category of software tools is the Core graphics package, a library of graphics subroutines which can be called from a FORTRAN program. These routines simplify the creation of complex displays, such as 3-dimensional perspective images, by breaking down high-level commands into the many simple, low-level steps required (8).

The third set of packages provided with the system are the programs that have been written by TSI to provide ultrasonic data collection, storage, analysis and display.

2.3 INTRA-SYSTEM COMMUNICATION

There are 3 communication links connecting the host and slave systems when they are being used together (as opposed to use in stand-alone mode). They allow the host to coordinate the actions of the various subsystems, and provide a path for data transfer between the 2 computers.

The first connection is a bi-directional RS-232 serial line between the scanner controller and the host computer. Using this link, the host sends commands and data to the slave to initialize the scan parameters and, after issuing a "scan" command, receives messages from the slave indicating that the scanning bridge has moved to the next position where ultrasonic data is to be collected. This link is also used by the slave to signal the host when it has completed execution of a command.

The second communication path is between the host computer and the ultrasonics subsystem, and consists of a simple trigger line that causes the currently selected transducer to be pulsed. Note that while this trigger is under control of the host, transducer selection is performed by the scanner controller (see Section 3.1 below for more information on the communication protocols used).

Finally, the third link is an analog signal line which passes an amplified, gated and processed echo signal from the ultrasonic subsystem to the host, for further processing and storage.

3. SYSTEM CAPABILITIES

3.1 SCANNING PROCEDURE

In order to see how the various subsystems interact, it would be useful at this point to go through the steps required to inspect a testpiece.

First, the operator must configure the ultrasonic subsystem for the desired scan. This involves connecting the required transducers to the pulser outputs and receiver inputs, connecting the desired receiver modules into the circuit (log or linear amplifier, video detector, etc.), and adjusting the gate delay and width for each transducer.

At the prompting of the host, the operator then enters the necessary scan parameters including the axes to be used, the dimensions of the scan, the axes velocities, the distance between samples, and the number of transducers to be used. The host, after verifying them, sends these values to the scanner controller. The operator must also enter parameters concerning the type of data that is to be collected (waveform, amplitude, or TOF), amplitude thresholds to be used (if applicable), etc.

Once all the required scan parameters have been entered, the host opens a file to hold the collected data. All the details of the scan are stored at the beginning of this file, in what is referred to as a file "header". After manually moving the scanning bridge to the starting position of the scan (using the scanner positioning controls), the operator then enters the host

command to begin.

From this point on, the host computer is responsible for coordinating the actions of the various subsytems. Every time the scanning bridge reaches a sampling position, the slave sends a message to the host. It is repeated once for each transducer that the slave has been instructed to use. As each message is sent, the scanner controller enables the respective transducer in the ultrasonic subsystem. Upon receiving each message, the host sends a trigger signal to the ultrasonics to pulse the currently selected transducer and sends a command to the DTR to initiate sampling. When the DTR has finished collecting the data, it informs the host computer, which then performs any processing required and stores the results in memory.

This sequence continues at each sample location until a single scan line has been traversed, at which point the host computer transfers the data values from memory to disk and waits for a message saying that the first data sampling point on the next scan line has been reached. The sequence is then repeated for this next scan line.

When the slave signals that the entire scan is complete, the host stores the data for the last scan line and closes the output file. This data file can then be transformed from a sequential series of time of flight data to a file of 3-D Cartesian coordinates. This second file is used as input for the graphics display programs.

3.2 DATA COLLECTION AND PROCESSING

When the DTR receives a trigger command from the host it first counts down the post-trigger delay, if one has been specified, before beginning digitization of the incoming waveform. The amplitude is sampled with 8 bit (1 part in 256) resolution and 4096 points along the ultrasonic waveform are collected (at sampling rates of 20 MHz or less) and stored in an intermediate buffer.

To sample at higher rates (which can be done only on repetitive waveforms) the DTR performs multiple digitizations of the signal, with each one having a post-trigger delay that is some fraction of the sample interval greater than the previous sample. For example, to digitize a 10 Mhz sine wave at a rate of 80 MHz, 4 complete 20 Mhz digitizations of the signal could be made. The first would have no post-trigger delay, the second would have a post-trigger delay of 12.5 ns, the third would have a delay of 25 ns, and the fourth a delay of 37.5 ns. On the assumption that each digitization is triggered at the same point on the waveform (which is why this is only valid for repetitive signals), the effect is that 4 x 4096 = 16,384 points have been collected, one every 12.5 ns, for an effective sampling rate of 80 Mhz.

When the DTR has finished sampling data it informs the host computer, which then either stores the entire data buffer (for waveform recording) or performs further processing according to the type of data initially requested (amplitude or TOF). For TOF recording, the host searches the buffer for the 2 largest peaks

having an amplitude greater than a predetermined threshold, and stores in memory their position within the buffer. These peaks, when present, are assumed to represent a front reference surface and a flaw or back reference surface. For recording of amplitude information, it is assumed that the operator has gated out the front and rear reference surfaces (since they are irrelevant in this case). Therefore, only a single value, corresponding to the amplitude of the largest peak found in the buffer, is stored.

Data points are stored as a linear array in the same sequential order in which they are collected, which eliminates the need to store the location of the scanning bridge for each point. The data file header contains, among other parameters, the distance between samples, the distance between scan lines and the number of samples per scan line. Since the scan pattern is known, these values allow the coordinates of any data point to be calculated knowing only its ordinal position in the array.

Similar methods are used to conserve storage space in the other types of data files. Using the values stored in the data file header for post-trigger delay and digitization rate, the position in time for both waveform amplitude data points and TOF buffer position data points can also be calculated.

3.3 INSPECTION MODES

There are 4 general types of displays that the system can produce:

i) 3-dimension TOF projection

ii) rf or video waveform (A-scan),

iii) modified C-scan (including beam profile),

iv) 2-dimension section/slice (including B-scan and C-scan).

3.3.1 3-Dimension Time-of-Flight Projection

Since the TOF from a transducer to a reflector is proportional to their separation, TOF data can provide flaw-depth information unavailable in an amplitude scan. Using simple orthogonal transformations, and knowing the geometry between the transducer and the testpiece during the scan, it is possible to convert the TOF and implied x and y positions of the scanning bridge for a given data sample into the x, y and z coordinates of the reflector.

There are three methods for time of flight scanning and display. All three methods filter out the front wall of an object being scanned and measure the TOF and amplitude of the second echo.

3.3.1.a Method 1 (Aluminum block)

The first method is a simple C-scan, which also records the time of flight. Method one can involve up to eight non-rotating transducers simultaneously scanning a stationary object. Figure 7 was scanned in this fashion and Figure 8 was generated from the data.

3.3.1.b Method 2

This method uses rotating transducers to C-scan a stationary object. Both direct and skip beams can be used. Figure 9 was

scanned by this method. The object was a milled piece of aluminum shaped like a kidney, which was C-scanned by a single rotating transducer. The data was transformed from time of flight data to Cartesian coordinates through a series of transformations (13).

The data was transformed from the transducer coordinates to the stationary tank coordinates through two subtransformations: $(x'',y'',z'') \longrightarrow (x',y',z') \longrightarrow (x,y,z)$. The distance (L) to the defect from the transducer is given by the time of flight (TOF) of the echo and sound velocity (V):

$$L = TOF \times V/2$$

The defect location may be specified in terms of the transducer coordinate system, based upon the transducer height (d) above the backwall, the transducer inclination angle (o') and the radius of rotation (p).

$$x'' = p + L \cos o'$$
$$y'' = o' \text{ (this defines the transducer plane)}$$
$$z'' = d + L \sin o' \text{ (for direct beam)}$$
$$z'' = -d - L \sin o' \text{ (for a skip beam off the backwall)}$$

The defect location may be transformed to the scanning bridge coordinates knowing the angular position (B) of the transducer.

$$x' = (p + L \cos o') \cos B$$
$$y' = (p + L \cos o') \sin B$$
$$z' = z''$$

In order to transform the scanning bridge coordinates to the tank coordinates, only bridge offsets from the tank origin need to be considered.

$$x = (p + L \cos o') \cos B + a$$
$$y = (p + L \cos o') \sin B + b$$
$$z = z'$$

For the experiment above, a coarse sampling was performed. The kidney was C-scanned to yield 32 X 32 sample positions. At each of these, the transducer was rotated 360° and sampled at 45° increments. A total of 8192 samples were taken. After transformation to tank coordinates, the 3-dimensional array of reflection points was plotted on a computer monitor. The display software permits a degree of noise rejection by plotting only those points whose echoes are over a specified amplitude threshold. It is also possible to plot direct and skip beam echoes separately. Figure 10 depicts top, front and side projections of the kidney in the lower right, upper right and upper left respectively. The lower left corner of Figure 10 shows the software generated representation of the data.

3.3.1.c Method 3

Method 3 can utilize rotating multiple transducers to C-scan a rotating object. Up to eight transducers can be used at the same time; more can be used with double multiplexing. Four transducers were used in scanning the heart in Figure 11; two to gather direct data and two long focus transducers for skip beam scanning.

Skip beams were reflected off a piece of stainless steel located beneath the test object, allowing the underside of the piece to be scanned.

Initially, a .3m X .3m X .06m plate of aluminum was used for a reflecting surface, but the signal to noise ratio was found to be too low. It was replaced by a .5m X .5m X .02m sheet of polished stainless steel. The amplitude of the signal was increased by a factor of 3 (Figures 12 and 13), which corresponds roughly to the ratio of acoustic impedance for aluminum ($Z = 17 g/cm^2-s$) and stainless steel ($Z \sim 50 g/cm^2-s$).

A heart (5.2cm wide, 3cm thick and 4.5cm high) was used for the experiment. The heart was manufactured from plastic for ease of milling, and wrapped in aluminum foil to enhance the ultrasonic reflectivity, then placed on a stand 12cm in height. The foil provided a better surface not only because of its superior reflective properties, but also its uneven topography. A smooth surface will reflect sound like a mirror. However, the crinkled foil reflected the signal in all directions and ensured that an echo would be received, irrespective of the angle of incidence.

The heart was C-scanned by four transducers attached to the scanning bridge. At regular displacement intervals along each C-scan line, the object was rotated 360°. The transducers were pulsed at fixed angle increments as the object was rotated. The transducers were set at 20° direct, 60° direct, 25° skip beam and 30° skip beam.

After the scan was complete, the data was constructed into the object through a series of transformations (14).

(x'',y'',z'') = Transducer coordinate system
(x',y',z') = Turntable " "
(x,y,z) = Object " "

The distance from a data point to the transducer (L) is given by

$$L = v \times TOF/2$$

where v is the velocity of sound in water, and TOF is the time of flight of the echo.

The location of the data points in the transducer's coordinate system is:

$$x'' = L \sin o''$$
$$y'' = 0$$
for direct beams: $z'' = h + L \cos o''$
for skip beams: $z'' = -h - L \cos o''$

where h is the transducer's height above the backwall, o'' is the transducer's angle from the normal, and y'' is defined as zero.

To transform into the turntable system:

$$x' = x'' - s$$
$$y' = y'' + d$$
$$z' = z''$$

where s is defined as the distance from the transducer to the turntable in the y''=0 plane, and d is the displacement from the transducer to the plane formed by the centre of the turntable, h, and the o arc.

$$x = x' \cos o - y' \sin o$$
$$y = x' \sin o + y' \cos o$$
$$z = z'$$

Selective gating was used to eliminate most of the errant noise by plotting only data points with amplitudes falling within a user defined window. The three-dimensional data was displayed from three viewpoints (top, side, and front) as shown in Figure 14. The software-generated representation was also displayed in the same picture on the CRT screen. The CRT presentation can be photographed to preserve colour, or printed on a printer using screen dump routines. By using multiple transducers at various

angles and software noise filtering a clearly recognizable representation of the heart was generated.

3.3.2 Waveform

This is the method used to display waveform data i.e., data collected from rf or video (A-scan) signals, that has been digitized and stored in its entirety. This provides the user with the equivalent of a digital storage oscilloscope, which can be used to record an echo sample from a larger TOF or amplitude scan for the purpose of noise-level evaluation, etc.

As an example, Figures 12 and 13 show video waveforms with multiple echoes (the transducer excitation pulse and subsequent ringing has been gated out). Waveforms can be easily expanded to display greater detail of a particular portion or feature of the data.

3.3.3 Modified C-Scan

Next to the normal C-scan (Section 3.3.4), the modified C-scan is one of the most common methods used to display echo amplitudes. Using a normal or oblique transducer, amplitude data is collected from a scan in the form of a set of amplitude profiles (one profile per scan line). If these profiles are plotted together on the same screen or page with each given a small horizontal and vertical offset from the previous one, the effect is similar to that of a 3-dimensional isometric projection.

Figure 7 is a drawing of a test block which was used for a number of demonstration scans. It is roughly cube-shaped, made of aluminum, and has a central milled slot, 2 side-drilled holes and 2 vertically drilled holes. Figure 15 shows a modified C-scan of this testpiece.

When viewing a modified C-scan, it must be kept in mind that the vertical axis represents magnitude of reflectivity, not the distance to the reflector (as is the case for a 3-dimension TOF data display).

Another example of a modified C-scan display is beam profiling, used to aid in the characterization of ultrasonic transducers. For this test, the centerline axis of the transducer is fixed parallel to the scanning plane. The transducer scans back and forth at increasing distances from a point target. The resulting data can be used to graphically show the relative ultrasonic beam strength at different points within the transducer's field. As an example, Figure 16 shows a beam profile of an unfocused 3.5 MHz transducer. In order to exaggerate certain features of the plot, it has been compressed in the direction of the centerline axis; the actual width and length of the scan are, respectively, 0.5" (1.3 cm) and 6.0" (15 cm).

3.3.4 2-Dimension Section/Slice

Amplitude or TOF data collected from a 2-dimensional scan is normally stored (either implicitly or explicitly) as a 3-dimensional array, with either amplitude or TOF as a function of x and y scanner position. This representation suggests that a

subset of a data file could be easily displayed as a section "cut" from the array, parallel to one of the 3 axes.

The common B- and C-scans are precisely this. Consider scanning in a coordinate system where scan lines are parallel to the x axis, indexing is in the y direction, and the data collected is along the z axis. A B-scan, then, is simply a y-z slice one scan line thick, cut from a TOF data array. Similarly, a C-scan can be considered as an x-y section extending from a minimum specified z (amplitude) value in the direction of the positive z axis. Figure 17 is a C-scan from the data file of Section 3.3.2, having a minimum threshold of 15% of full scale amplitude.

The advantage to considering B- and C-scans in these more general terms is that other similar, equally useful, display methods become apparent. For example, Figure 18 is a display much like a C-scan, except that it shows a slice through the z axis of a TOF data array (from Section 3.3.2), rather than being based on amplitude data. Whereas a C-scan shows all defects having a reflection amplitude greater than a certain threshold, this TOF slice displays only those defects intersecting a particular plane.

3.3.5 Image Display Graphics

There were two different methods of plotting 3-D scans. The first represents the data with a rectangular box defined by the least squares fit of the data. The block cube in Figure 8 was generated in this fashion.

There are three steps to calculating the least squares fit. First, the user must set the distance threshold range. The second stage is the grouping of the data. Finally, the least squares rectangle for each group is calculated.

When grouping the data, the distance between data points is calculated. All of the data points which are in close proximity as defined by the user's threshold range are grouped together as one large volume. The grouping algorithm defines the first data point in the file as being group number one. It then calculates the distance between group one and the second data point. If this distance is less than a predefined radius multiplied by $(\text{points in group})^{1/3}$, the point is made part of group one as follows:

```
        n = number of data points in group
(x,y,z) = position of the group
[x,y,z] = position of the point

(x,y,z) = n (x,y,z) + [x,y,z]
      n = n + 1

(x,y,z) = (x,y,z) / n
```

If the point's displacement from the group is outside the desired range then it is compared to the next group. The process continues until the point is either joined with an existing group, or, if none are within the threshold radius, it is made the first member of a new group.

After all of the points have been grouped, the process is repeated to find the displacement between each of the groups and joining those which are close together. By keeping the predefined radius small, many subgroups are formed by the first

step. The formation of these intermediate groups of data helps to filter out errant points, and allows for flaws which are close together to be grouped separately. In the case of the block cube, four groups of points were found. Once the groups have been defined, the program finds the least squares best line through each group of data points. The standard deviation of the line's slope and its length are used to define the rectangular box.

The second method was used to find the geometric representations of both the kidney and the heart. In this method, the user must first set the threshold amplitude range for the data. Data points from areas (such as the backwall), which are known not to be part of the object, may be eliminated by defining a volume of interest. The user sets maximum and minimum values for the x,y and z coordinates, and only points which are inside the limits are used to define the representation of the object.

3.3.6 Multi-Channel Scanning

Data from multiple transducers is processed by treating each transducer separately; relevant parameters are specified individually for each transducer, with the data for each transducer processed accordingly. Data from individual transducers can be combined for display purposes. The multiplexing reduces the speed of scanning considerably, but valuable information is gained. This data cannot be obtained with any single transducer scanning.

4. SUMMARY

In the course of this work an automated ultrasonic inspection system for immersion scanning has been developed and built. Important features of the system are the use of a high-speed analog-to-digital converter for data acquistion, and extensive computer processing for display and storage of the ultrasonic data.

The ultrasonic subsystem allows eight rotating transducers to be simultaneously collecting data from a revolving object. Several different modes of collection are available: echo, transmit and receive, tandem etc. Rf and video signal data can be stored in its entirety, or amplitude and time-of-flight information extracted.

The stored time-of-flight data can be displayed in a 3-dimensional perspective, and the physical location of defects is determined to within one centimetre.

Standard A-scans, B-scans and C-scans, as well as modified C-scans can also be displayed, making the information easy to comprehend.

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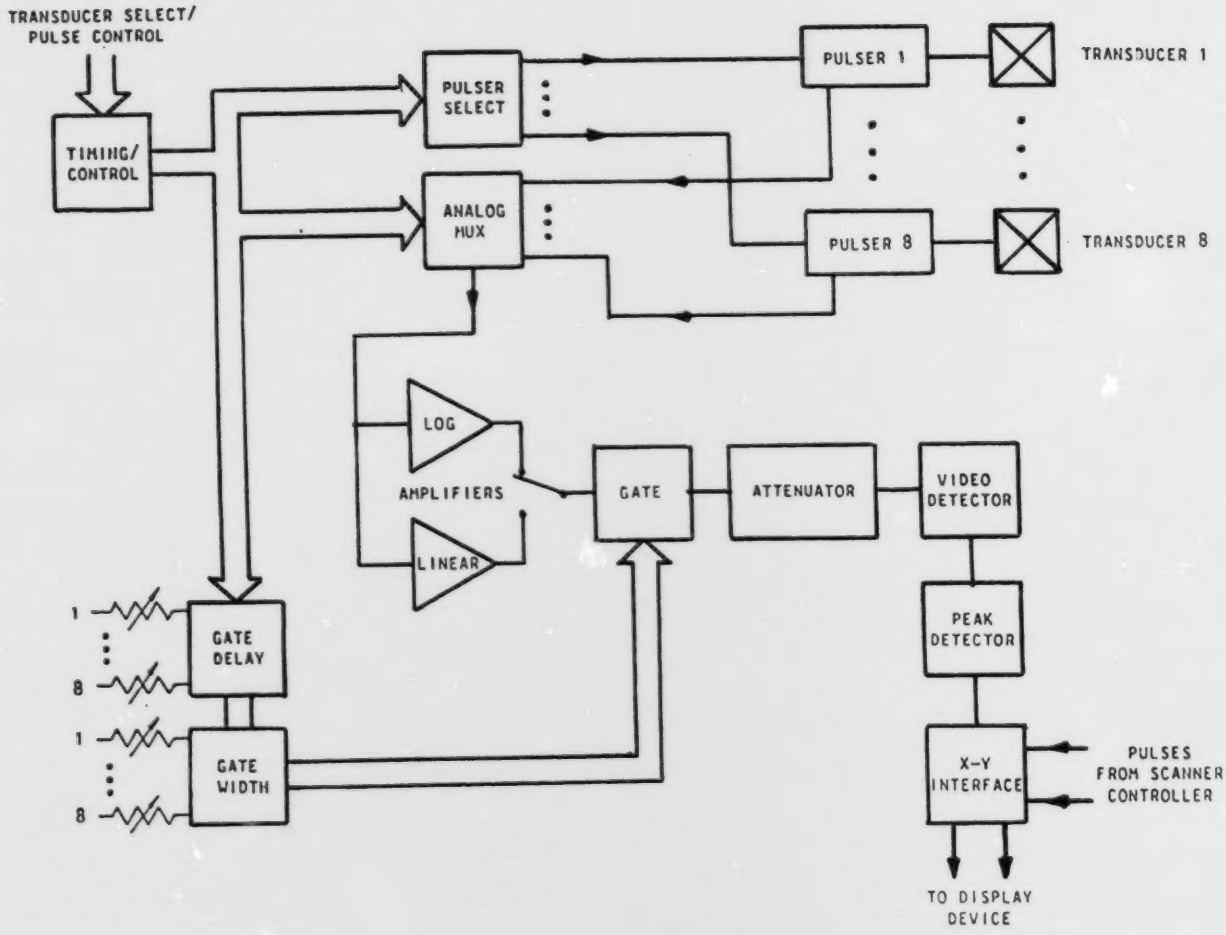

Figure 1 System Block Diagram

Figure 2 View of the Scanning Bridge and Immersion Tank

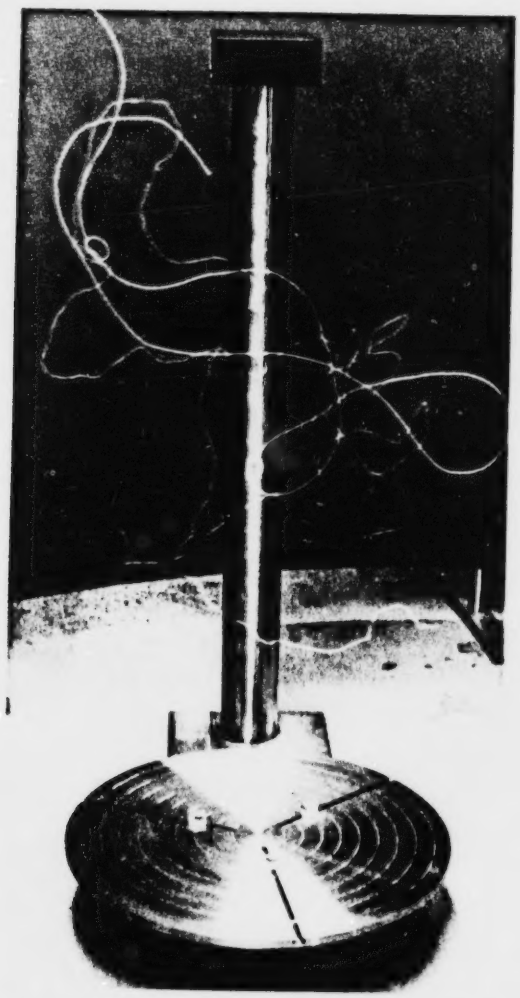

Figure 3a Drop-In Turntable Unit

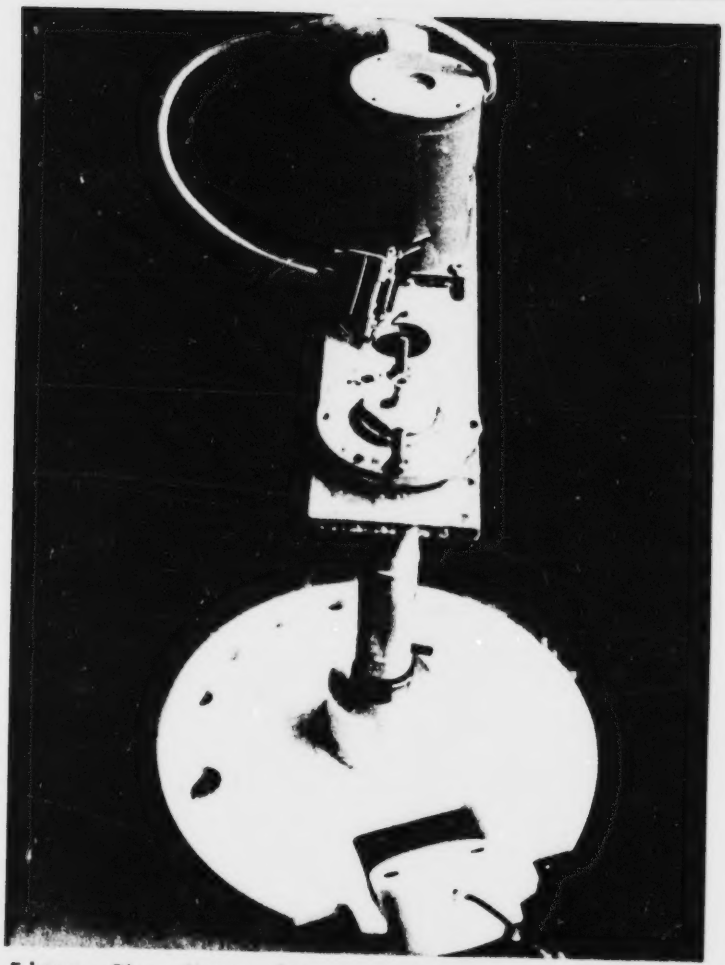

Figure 3b Mast with rotating transducer disk

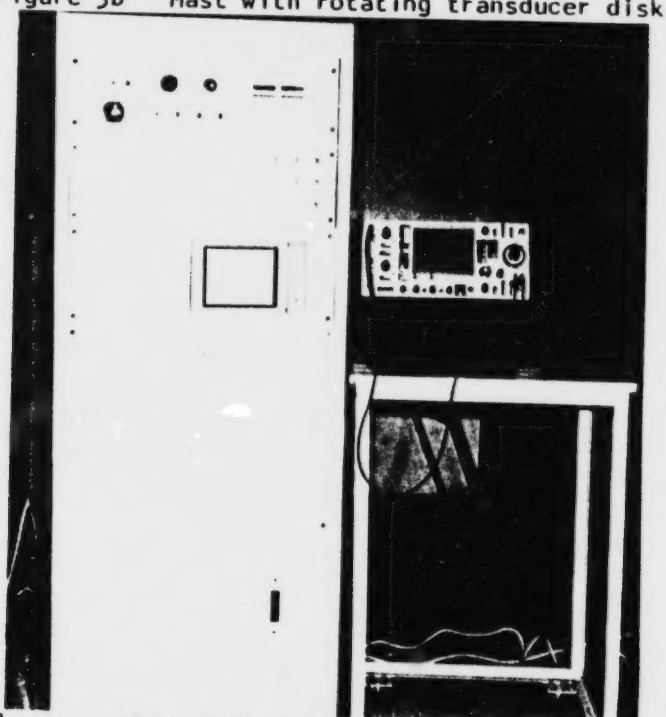

Figure 4 Slave System, including the Ultrasonics and Scanning Control Subsystems

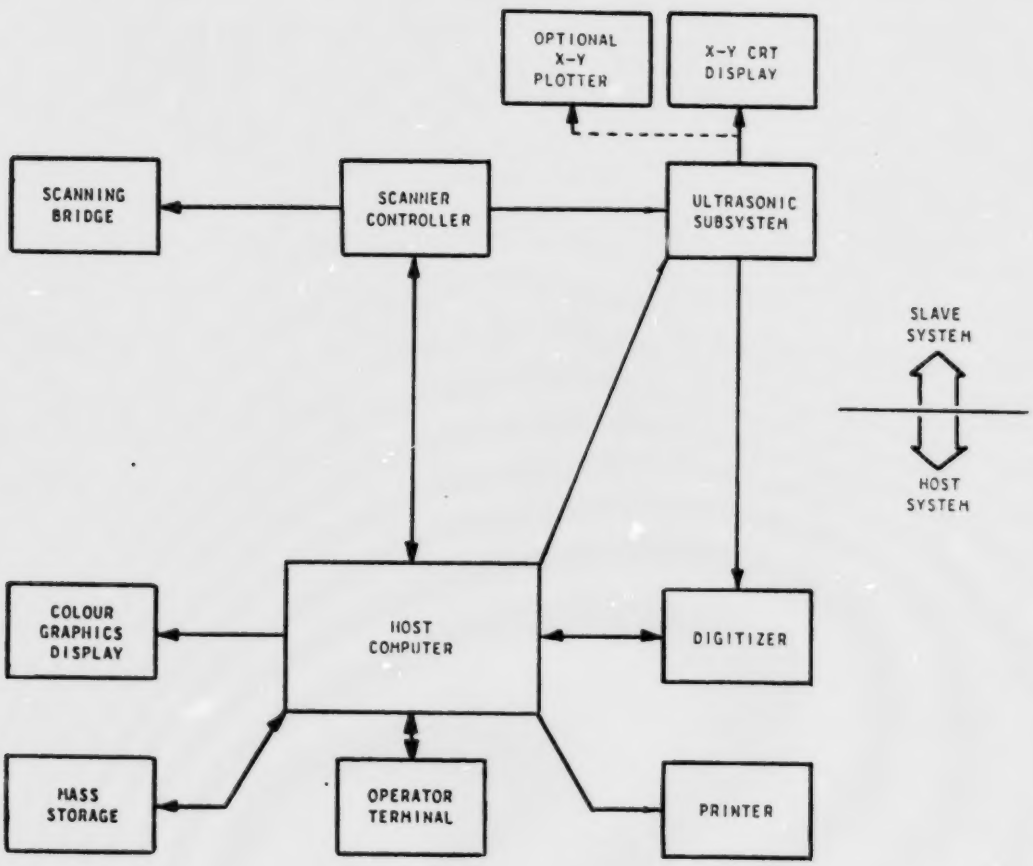

Figure 5 Block Diagram of Ultrasonic Subsystem

Figure 6 Ikier Eagle I Graphics Computer, with High Resolution Colour Monitor

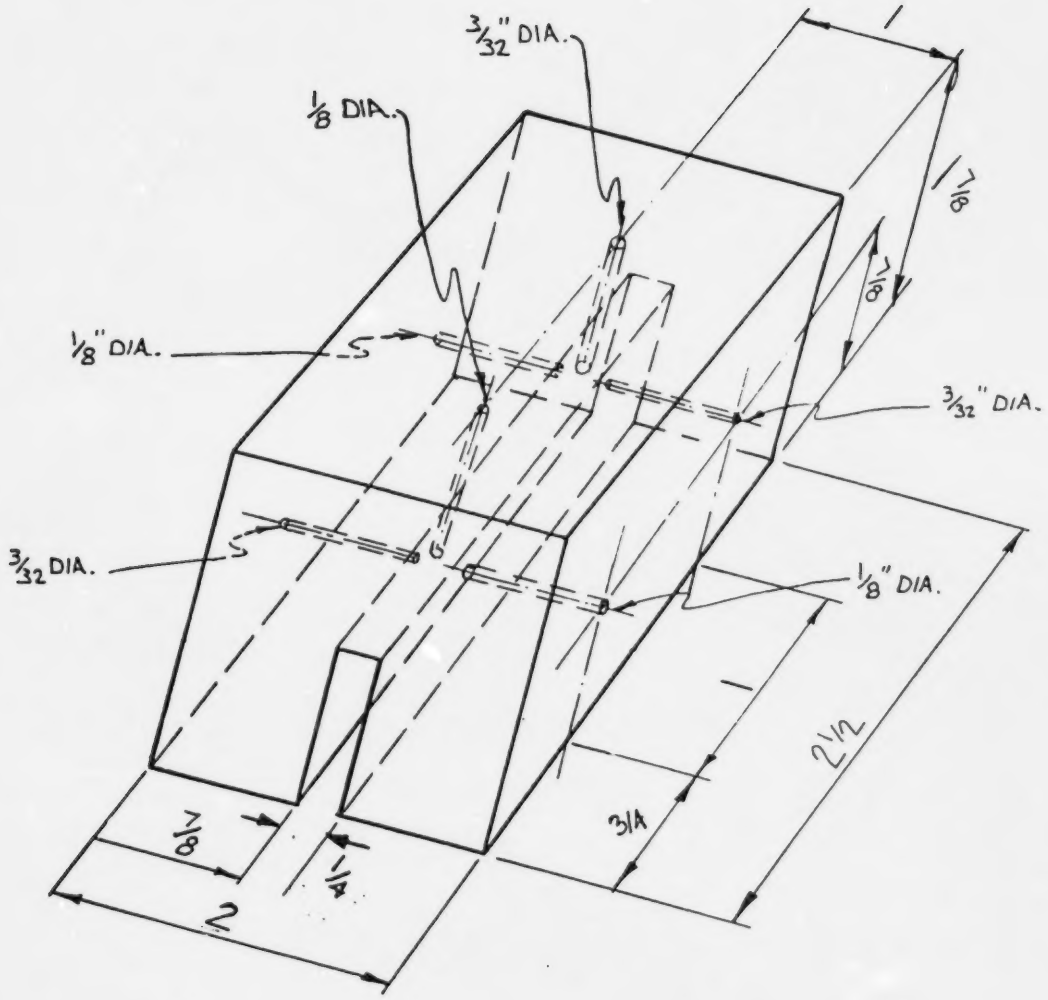

Figure 7 Drawing of the Test Block

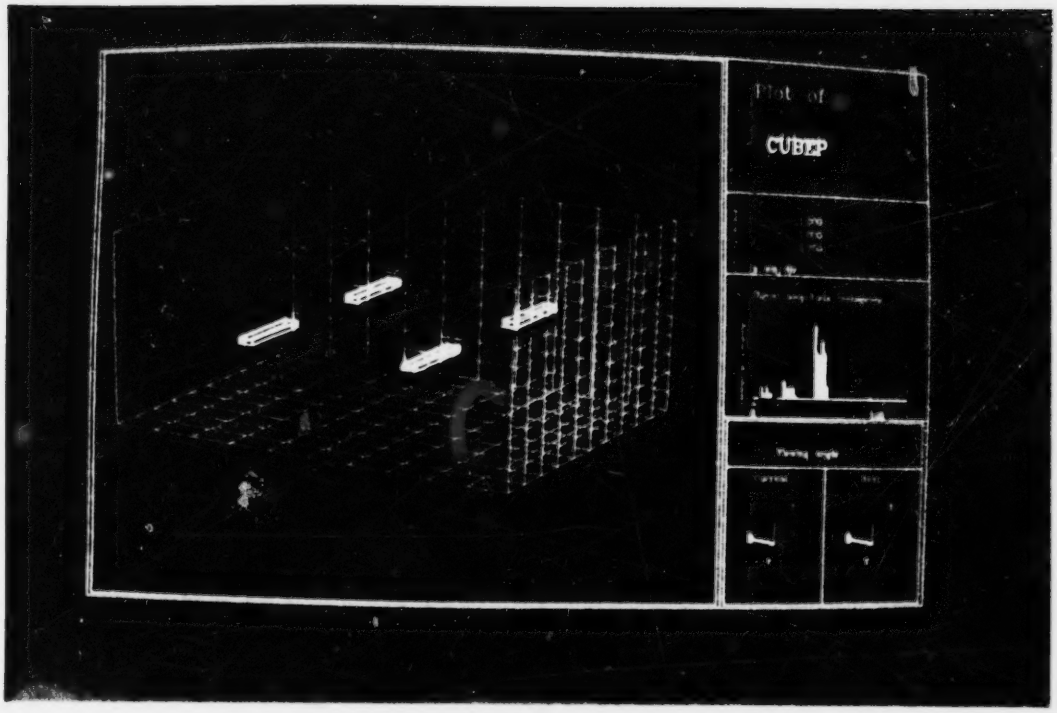

Figure 8 Display of the test block

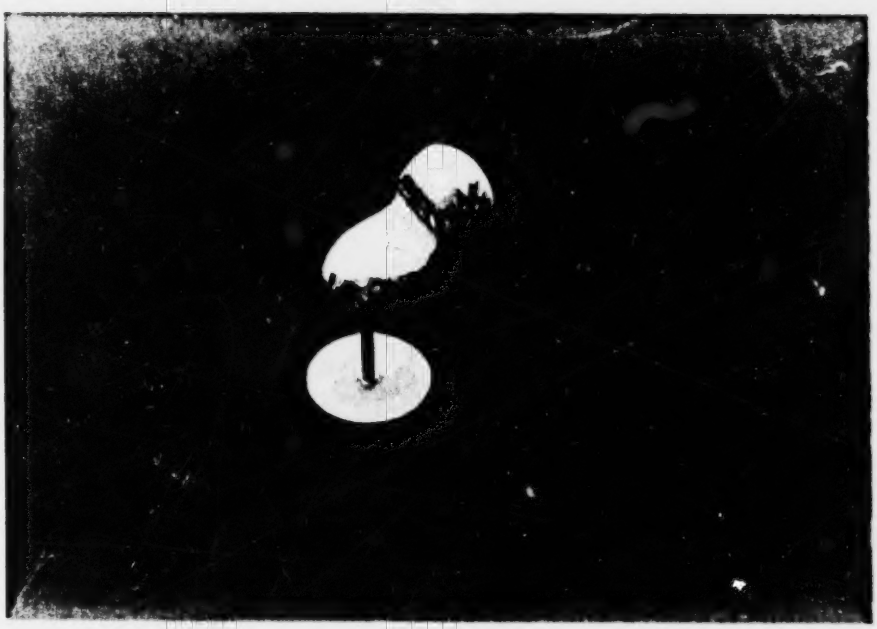

Figure 9 Photo of kidney

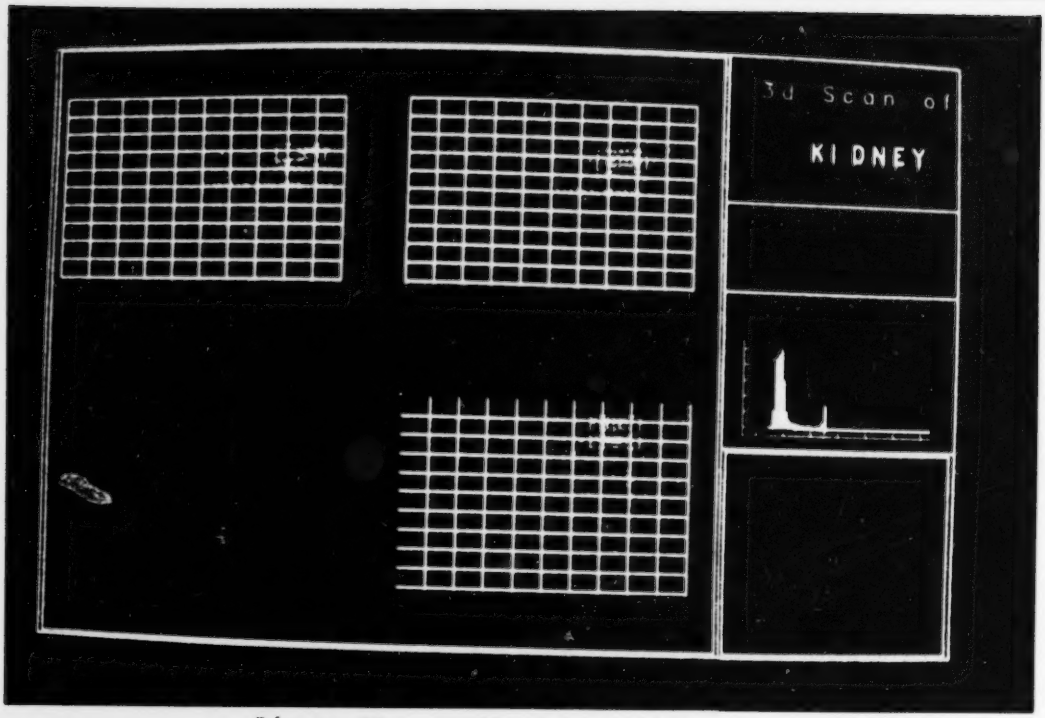

Figure 10 Display of Kidney

Figure 11 Photo of the Heart

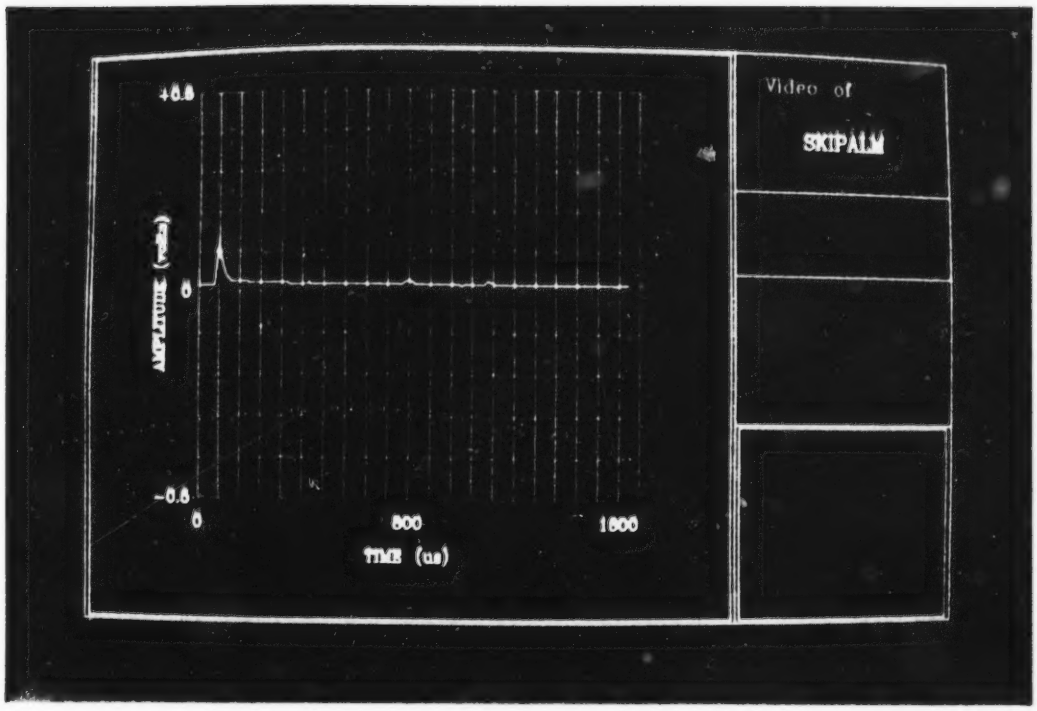

Figure 12 Video of Skip beam off stainless steel to the heart

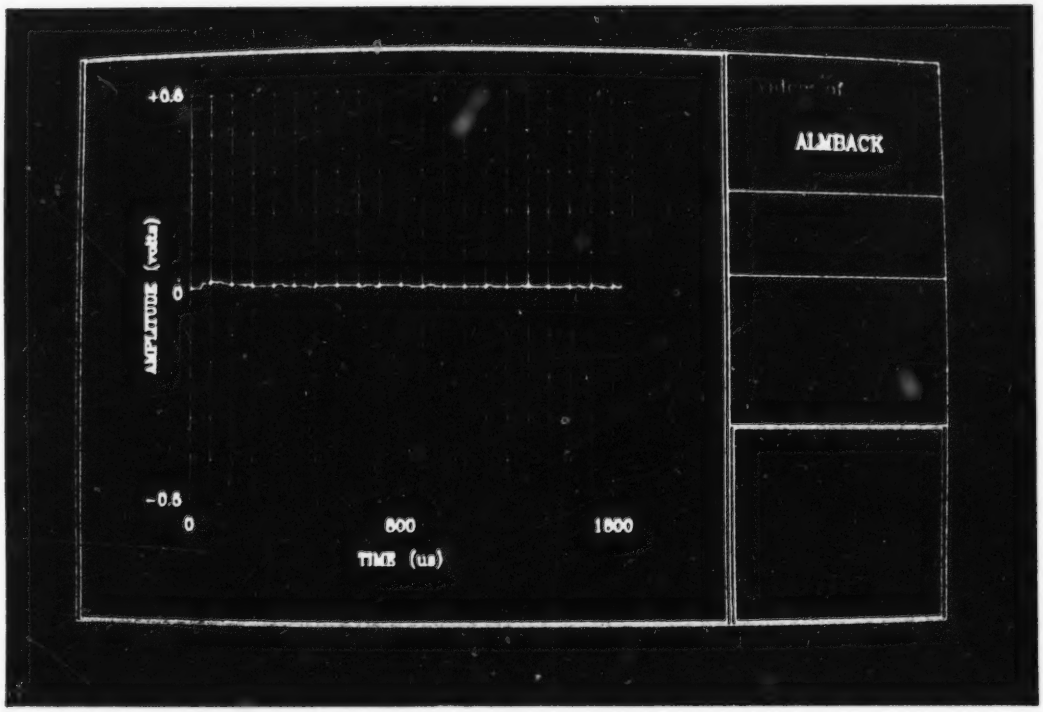

Figure 13 Video of skip beam off aluminum to the heart

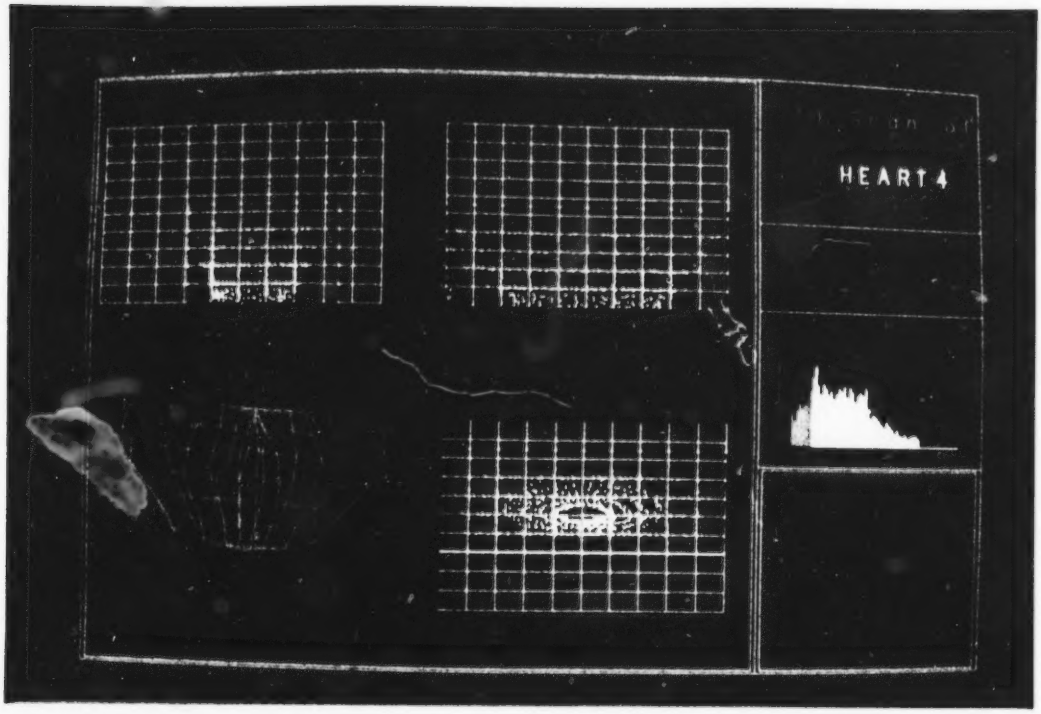

Figure 14 Display of Heart

Figure 15 Display of modified C-scan of test block

Figure 16 Beam profile of a 3.5 MHz transducer

Figure 17 Display of a C-scan of the test block

Figure 18 Display of X-Y slice (through Z axis) from test block 3-dimensional time of flight data

APPENDIX A - System Specifications

PHASE I

1. You shall design, assemble and proof test an ultrasonic system having the following components:

   a. a scanning bridge with X, Y, Z, movement;

   b. an immersion tank, with a motorized turntable controlled by a microprocessor;

   c. a microprocessor-based programmable scanning controller allowing for setting of the scanning pattern, scanning speeds and limits;

   d. an ultrasonic multiplexing system which shall multiplex up to eight transducers. Included shall be individual pulsers and gates for each channel;

   e. a programmable high speed analog to digital (A/D) converter.

2. The system shall be proof tested and shall meet the test specifications, hereunder, using the two test blocks to be supplied by the Department of Energy, Mines and Resources, as follows:

   a. using the steel test block sample of thickness fifteen (15) centimetres and containing eight artificial defects of dimensions 2.5 cm X 0.6 cm X 0.8 cm, arbitrarily oriented, the system shall be capable of locating the defects, with a signal-to-noise ratio no worse than that detected by manual inspection using a commercial ultrasonic unit USIP II;

b. using the heavy section weldment test block of thickness fifteen (15) centimetres, the system shall be capable of detecting center-line-cracking and lack-of-fusion defects in the weld.

PHASE II

1. You shall develop the data processing system and software for the control and operation of the ultrasonic tester system. The data processing system shall allow the location of defects and the presentation of a three-dimensional perspective of the test block or a two dimensional image of any cross section of the test block.

   The location of the defects using the normal beam method in X, Y, Z directions, angled beam method and tandem method shall be within error of +/- one (1) centimetre.

PHASE III

1. You shall write a computer program (both reflection and transmission) for ultrasonic tomography and demonstrate its feasibility to size defects in a test block.

2. Design and build scanning bridges for transmitters and receivers for the Ultrasonic Testing System designed and built under Phases I and II, for data logging for ultrasonic tomography.

A circular array of nine transducers shall be built and attached

to central mast. The array shall be rotatable while simultaneously rotating the turntable. A three-dimensional image of the defect shall be produced. The error in the location of the defect shall be within +/- 1cm.